ESC102T : Introduction to Electronics

L9: Capacitive and Inductive Circuits

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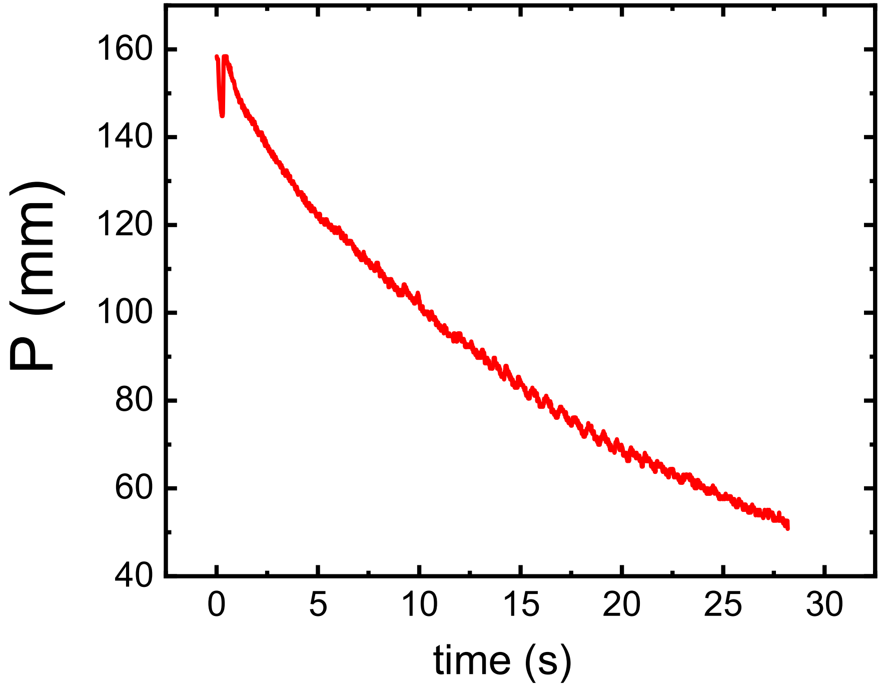
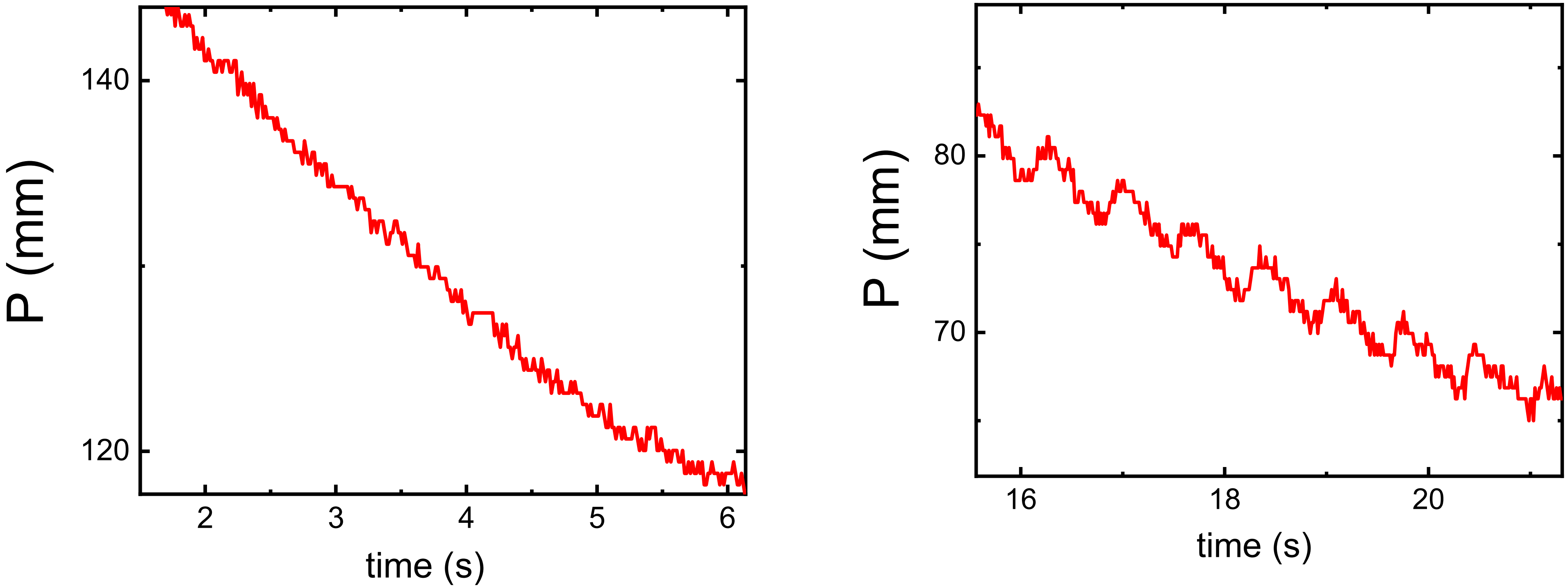
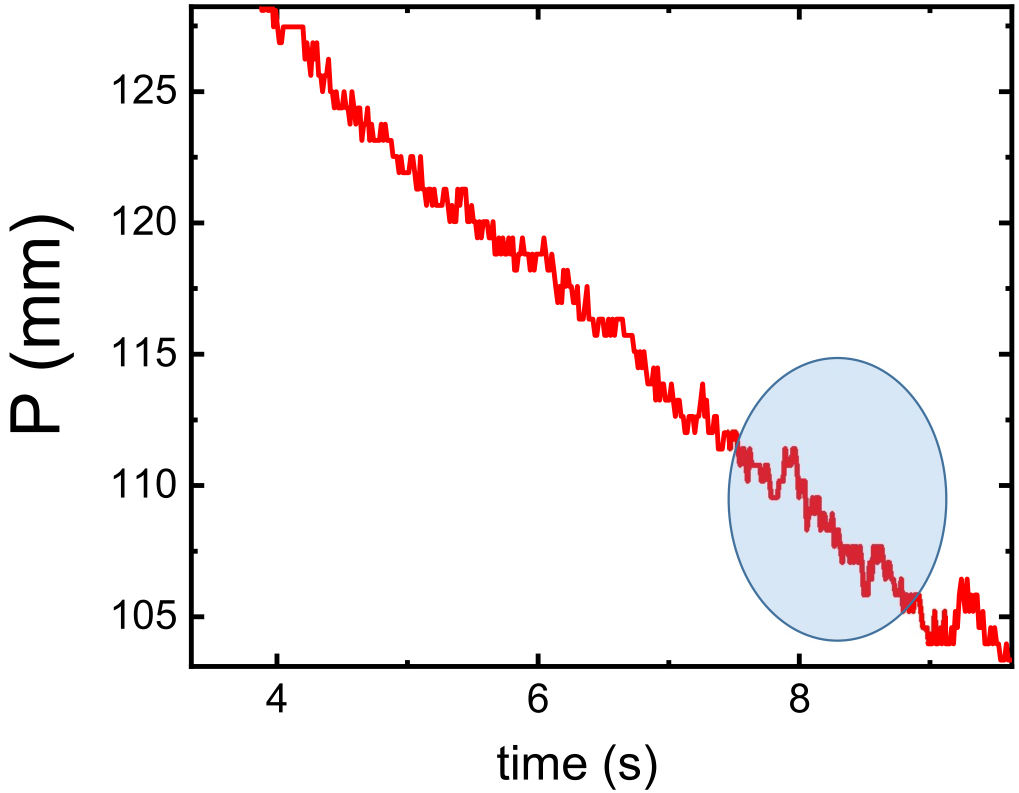
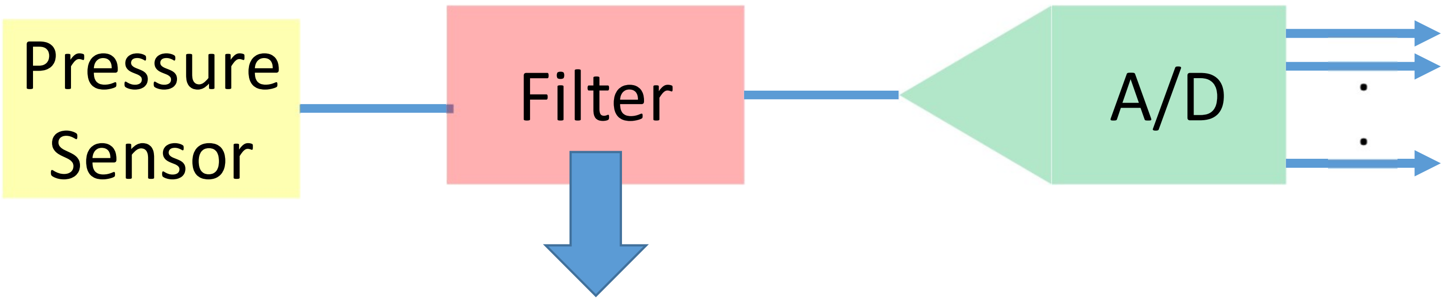
“All of you are carrying billions of capacitors in your pocket”


142
MARK

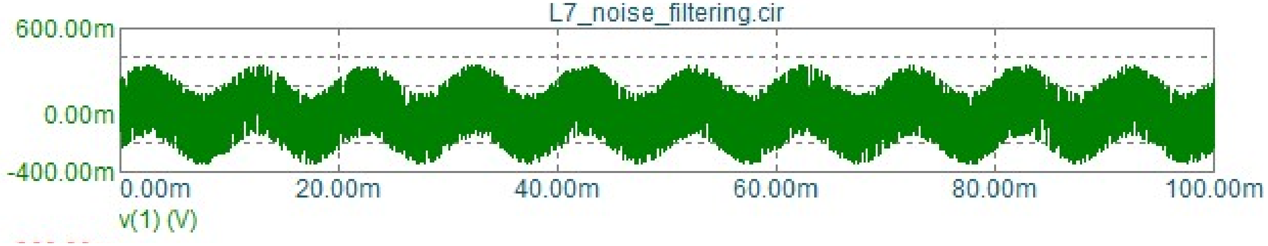

P (mm)
160
140
120
100
80
60
40
0
5
10
15
20
25
30
time (s)

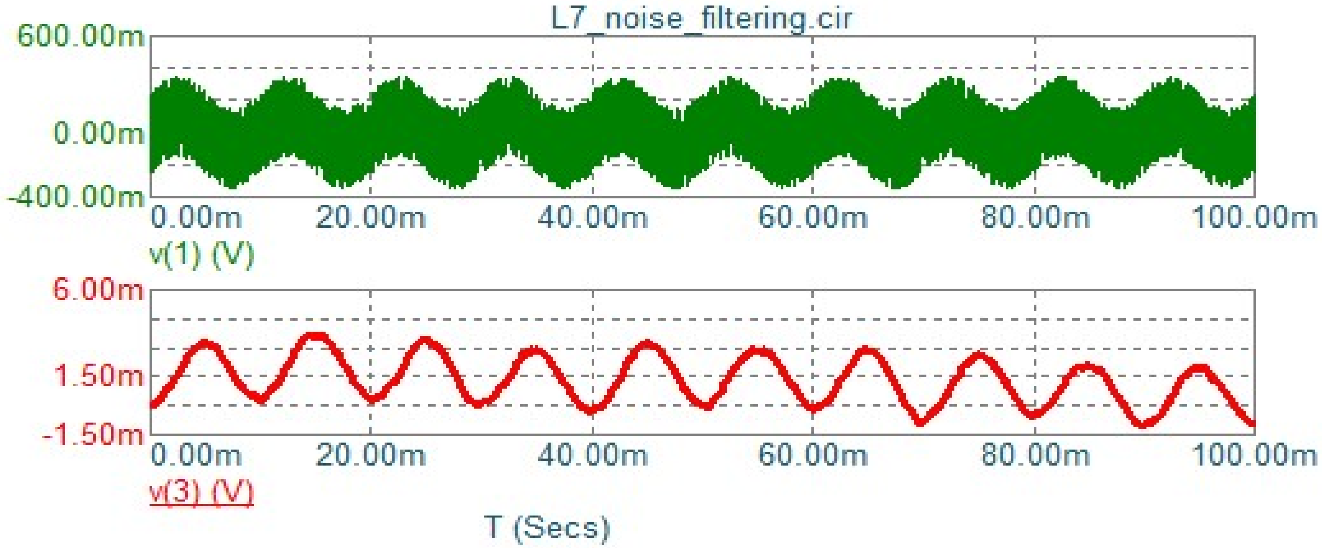

140
120
P (mm)
2
3
4
5
6
time (s)
80
70
P (mm)
16
18
20
time (s)

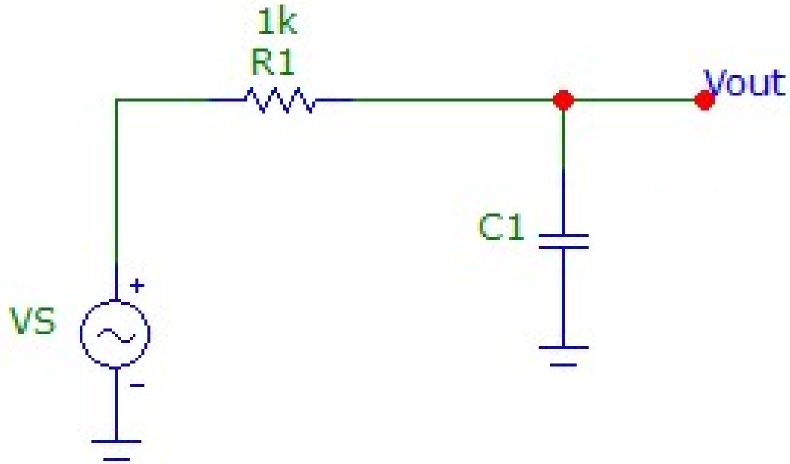


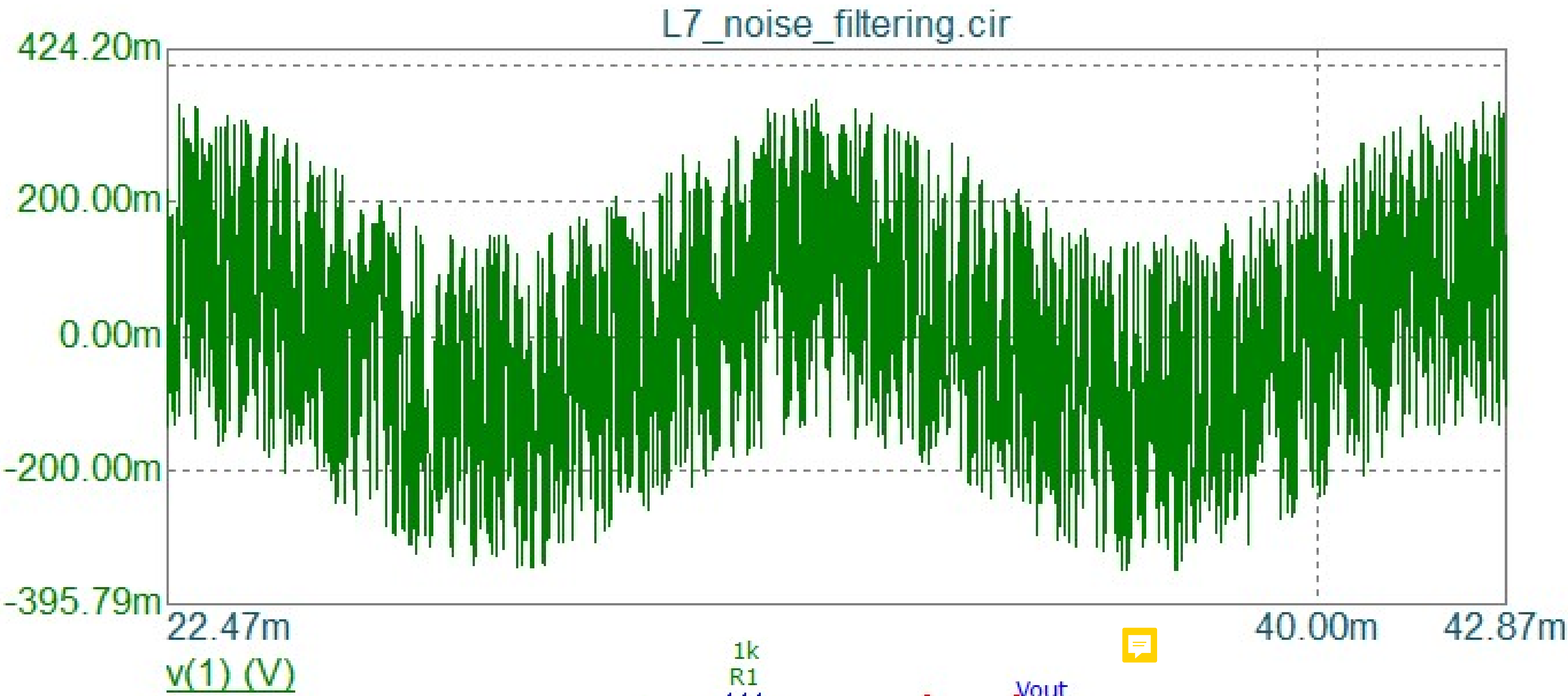


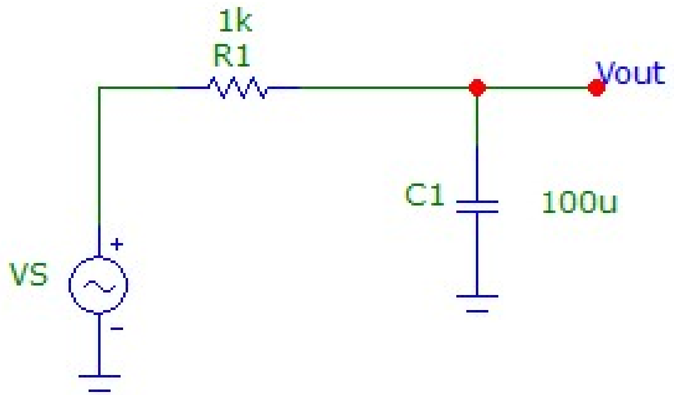
Variations over three different time scales are visible, only one of which is signal of interest

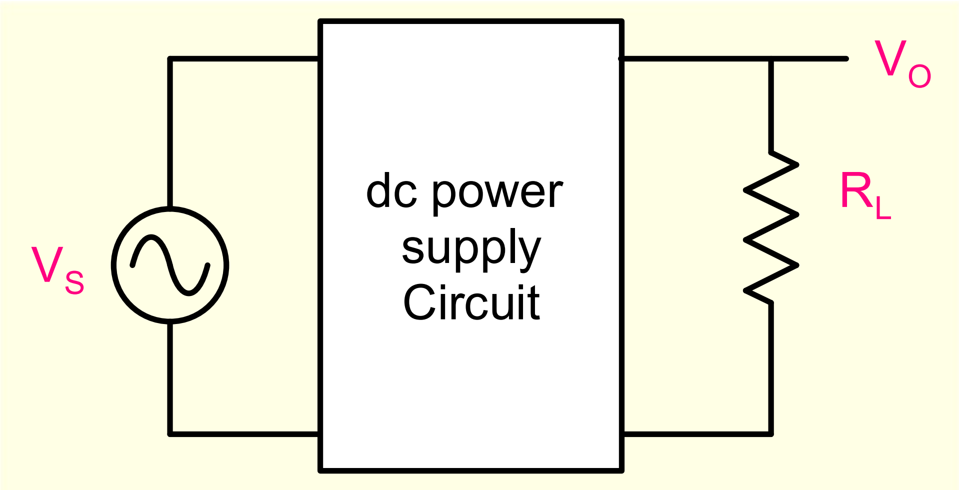

L7_noise_filtering.cir
600.00m
0.00m
-400.00m
0.00m
20.00m
40.00m
60.00m
80.00m
100.00m
v(1) (V)

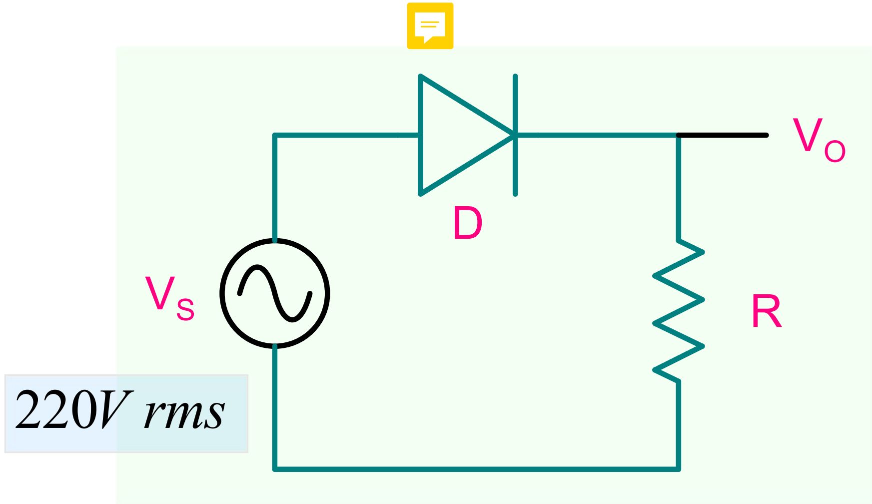

L7_noise_filtering.cir
600.00m
0.00m
-400.00m
0.00m
20.00m
40.00m
60.00m
80.00m
100.00m
v(1) (V)
6.00m
1.50m
-1.50m
0.00m
20.00m
40.00m
60.00m
80.00m
100.00m
v(3) (V)
T (Secs)

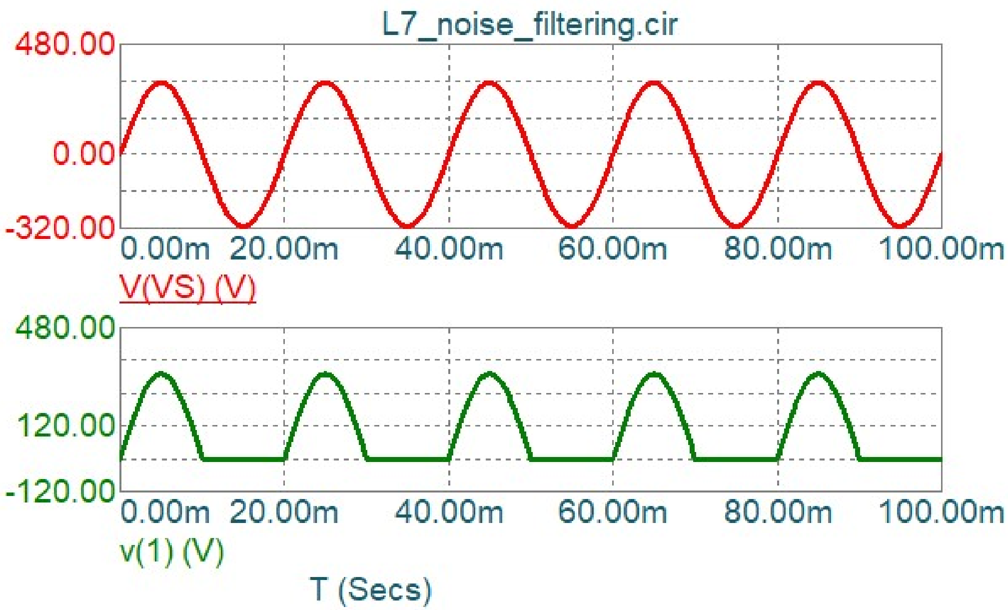

1k
R1
Vout
C1
VS
+
-

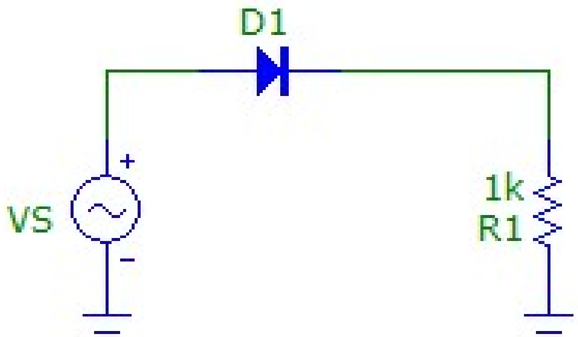

L7_noise_filtering.cir
424.20m
200.00m
0.00m
-200.00m
-395.79m
22.47m
40.00m
42.87m
v(1) (V)

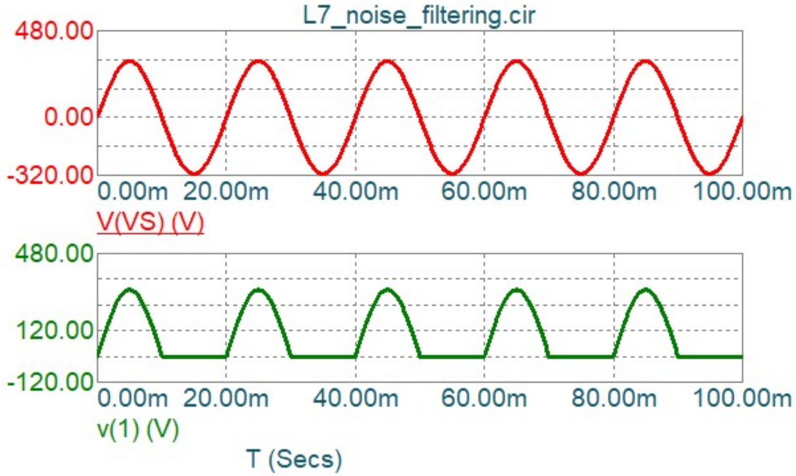

1k
R1
Vout
C1
100u
VS
+
-

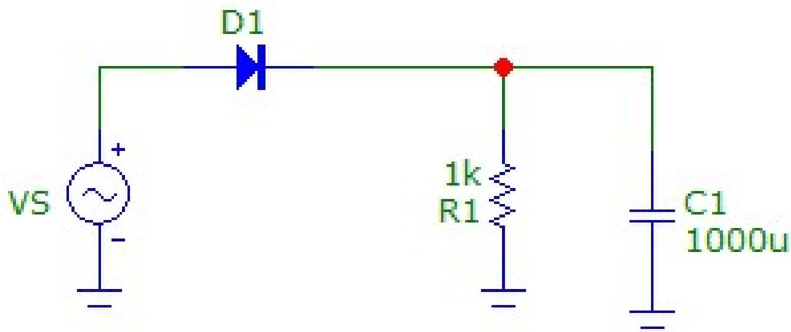

V_S
dc power supply Circuit
V_O
R_L

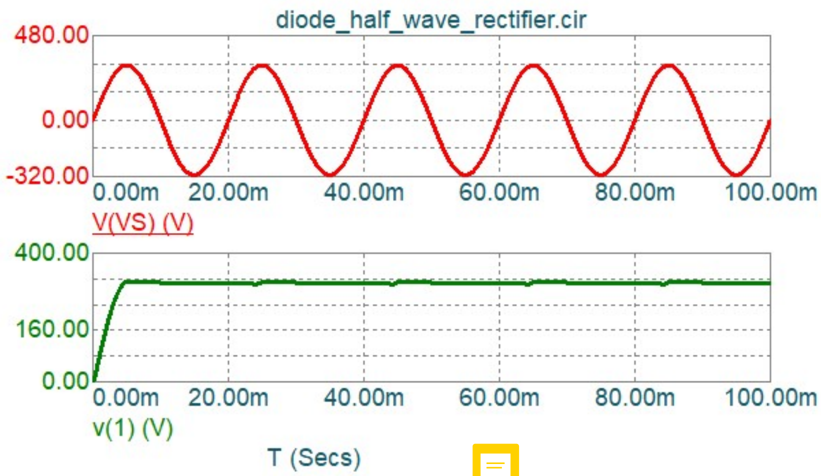

D
V_O
V_S
R
220V rms


L7_noise_filtering.cir
480.00
0.00
-320.00
0.00m 20.00m 40.00m 60.00m 80.00m 100.00m
V(VS) (V)
480.00
120.00
-120.00
0.00m 20.00m 40.00m 60.00m 80.00m 100.00m
v(1) (V)
T (Secs)


D1
VS
1k
R1

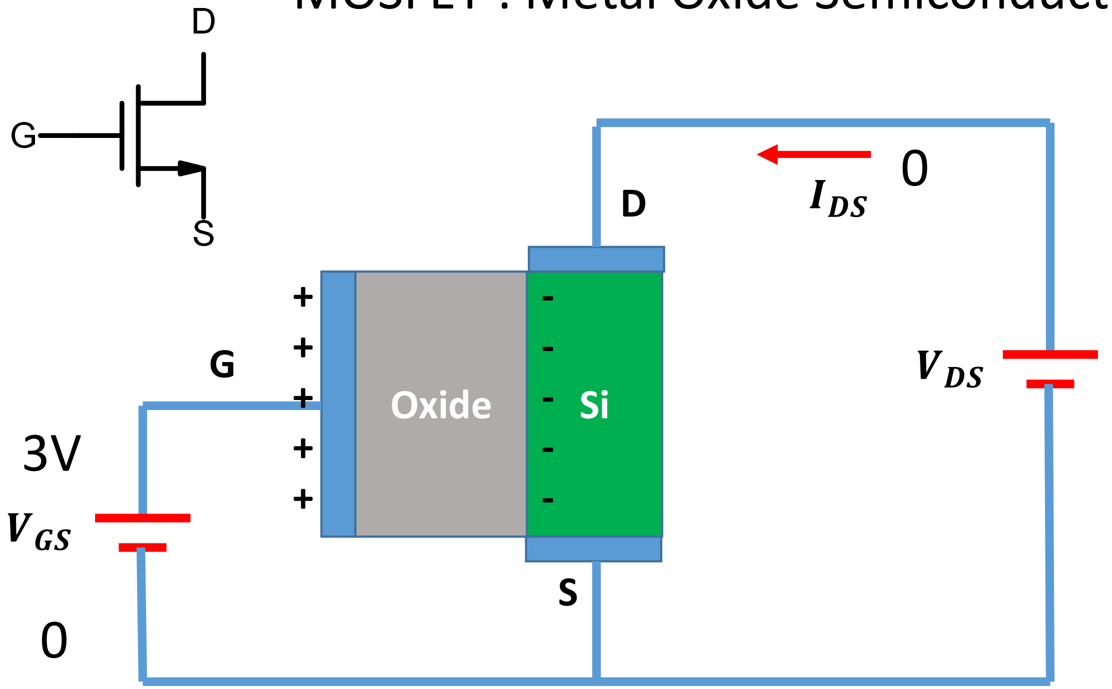

L7_noise_filtering.cir
480.00
0.00
-320.00
0.00m 20.00m 40.00m 60.00m 80.00m 100.00m
V(VS) (V)
480.00
120.00
-120.00
0.00m 20.00m 40.00m 60.00m 80.00m 100.00m
v(1) (V)
T (Secs)

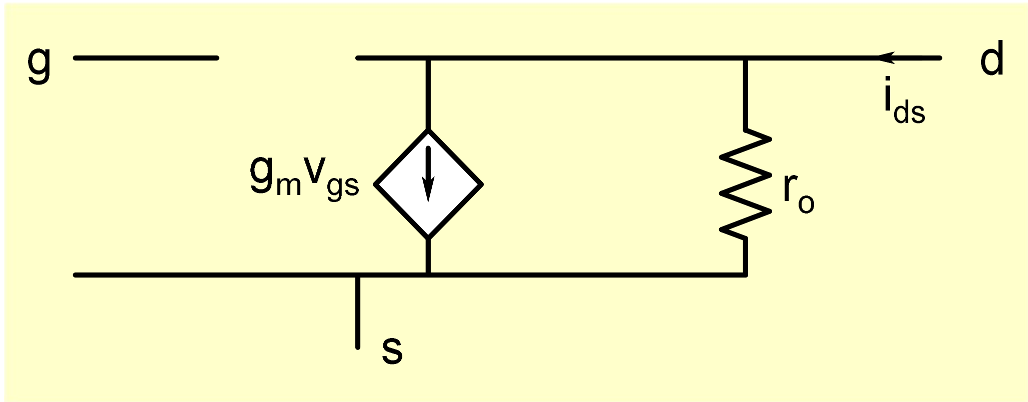

D1
VS
1k
R1
C1
1000u


diode_half_wave_rectifier.cir
480.00
0.00
-320.00
0.00m 20.00m 40.00m 60.00m 80.00m 100.00m
V(VS) (V)
400.00
160.00
0.00
0.00m 20.00m 40.00m 60.00m 80.00m 100.00m
v(1) (V)
T (Secs)

Fundamental Principle underlying Modern electronics is charge/discharge of a capacitor

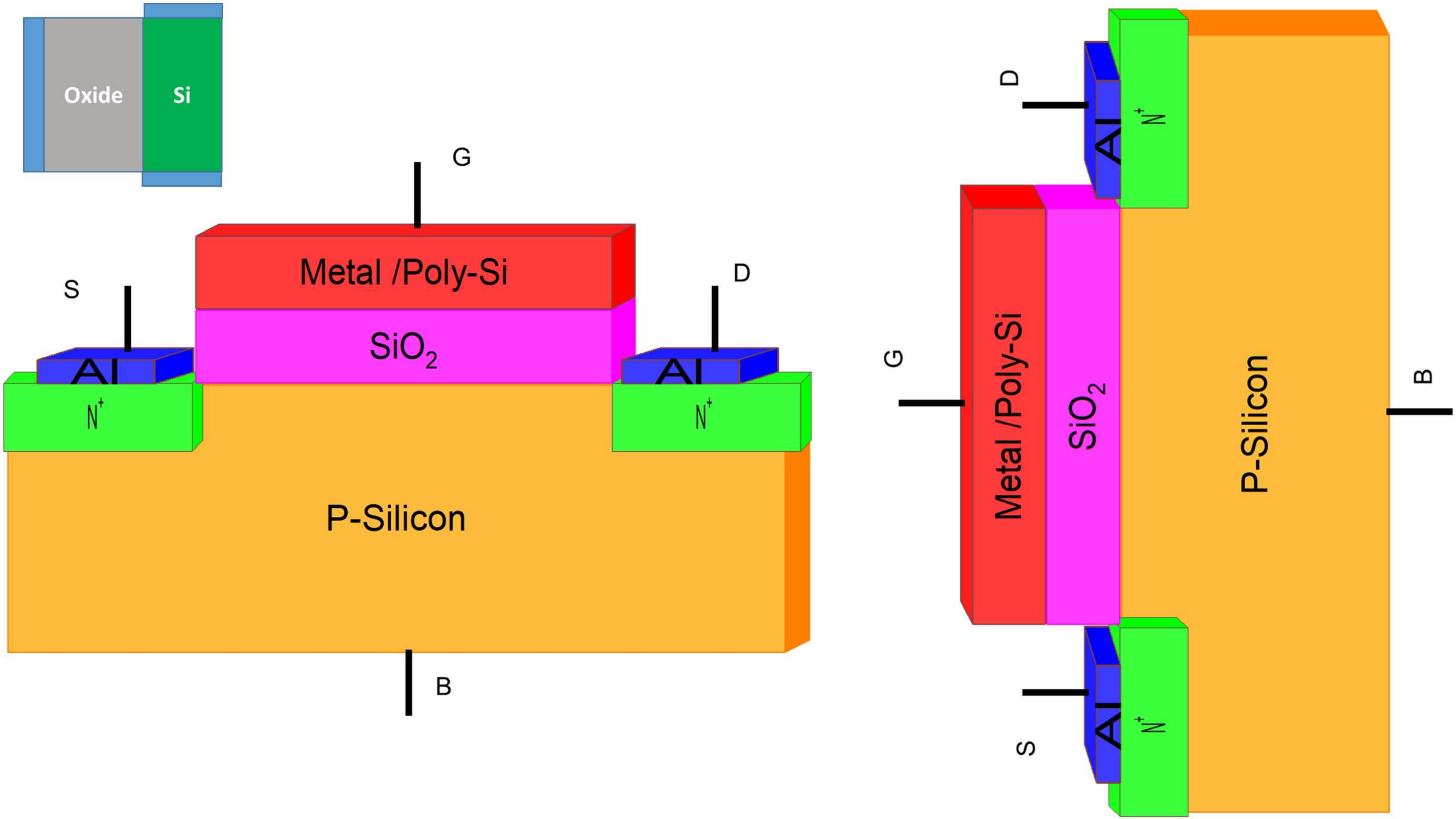
MOSFET : Metal Oxide Semiconductor Field effect Transistor

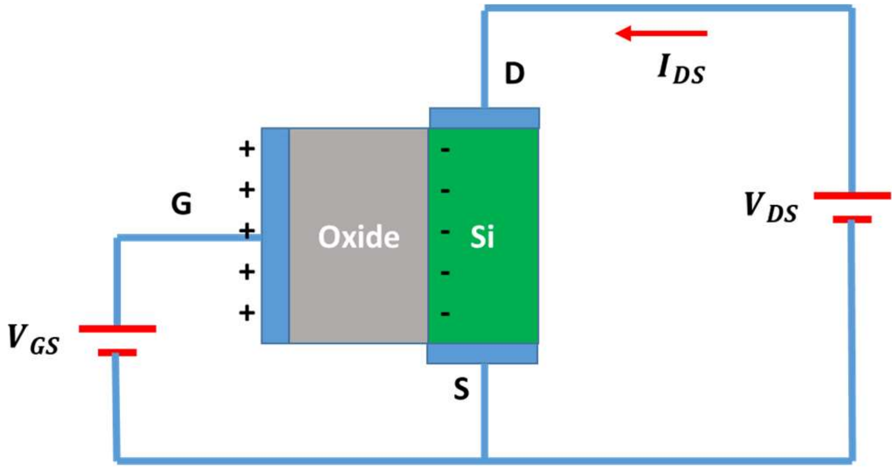




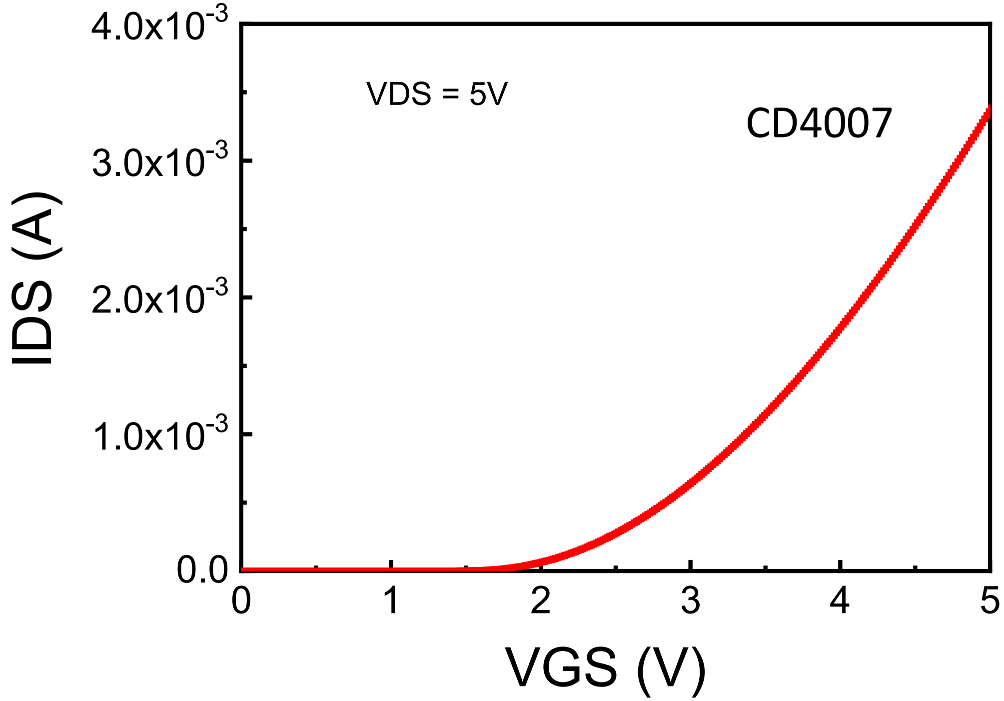
Voltage controlled current source

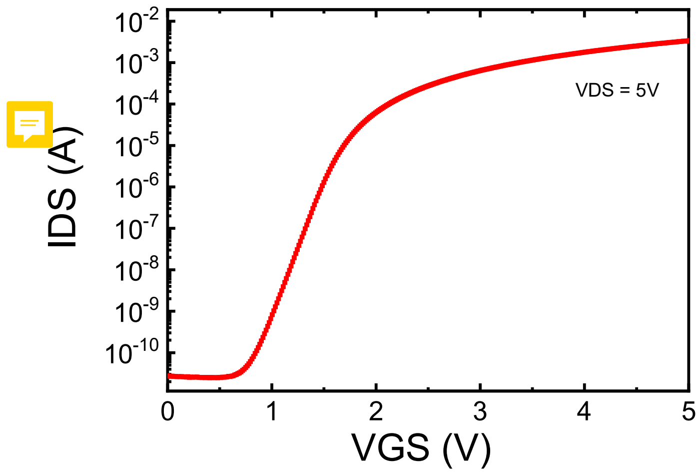
Drain current is controlled by gate voltage

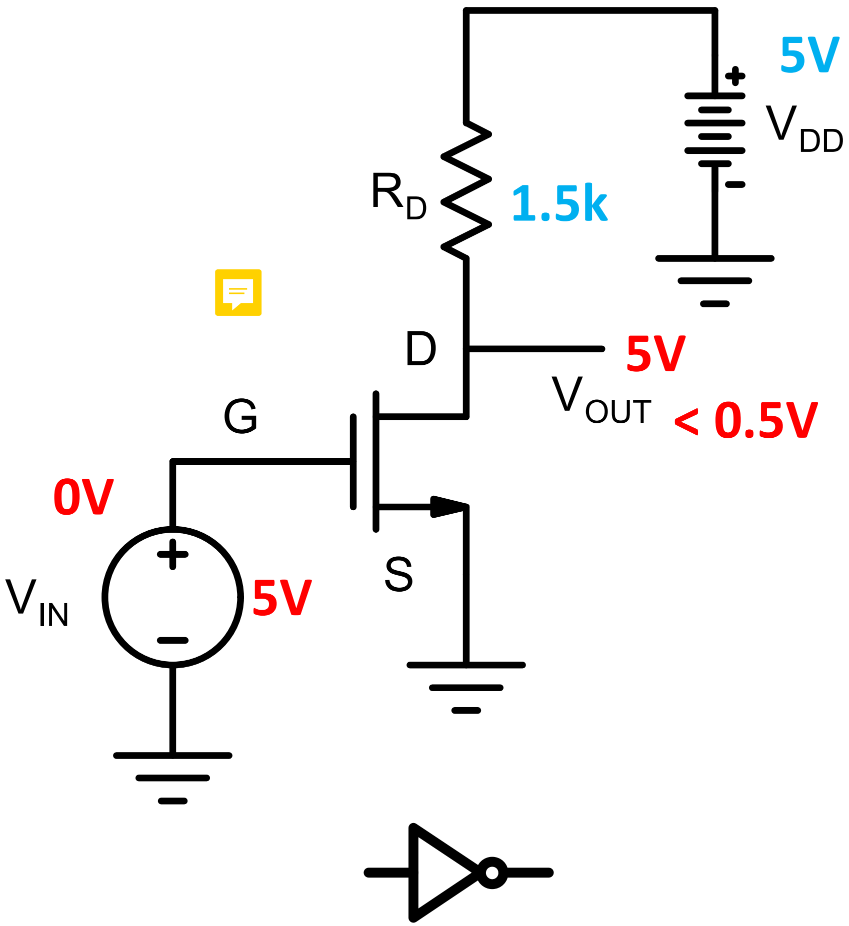

Oxide
Si
G
Metal /Poly-Si
S
D
SiO_2
Al
Al
N^+
N^+
P-Silicon
B
D
Al
N^+
G
Metal /Poly-Si
SiO_2
P-Silicon
B
Al
N^+
S

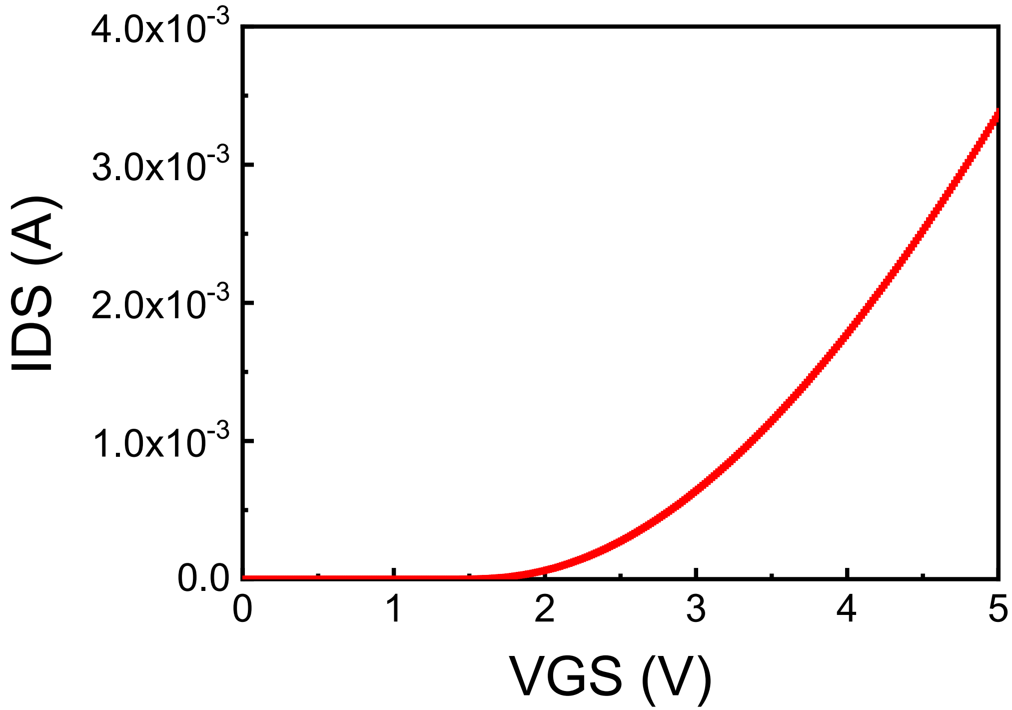


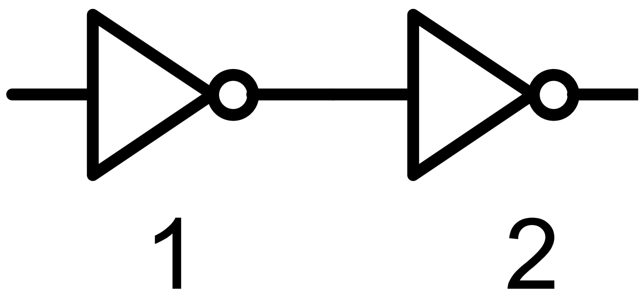
Drain current is controlled by gate voltage

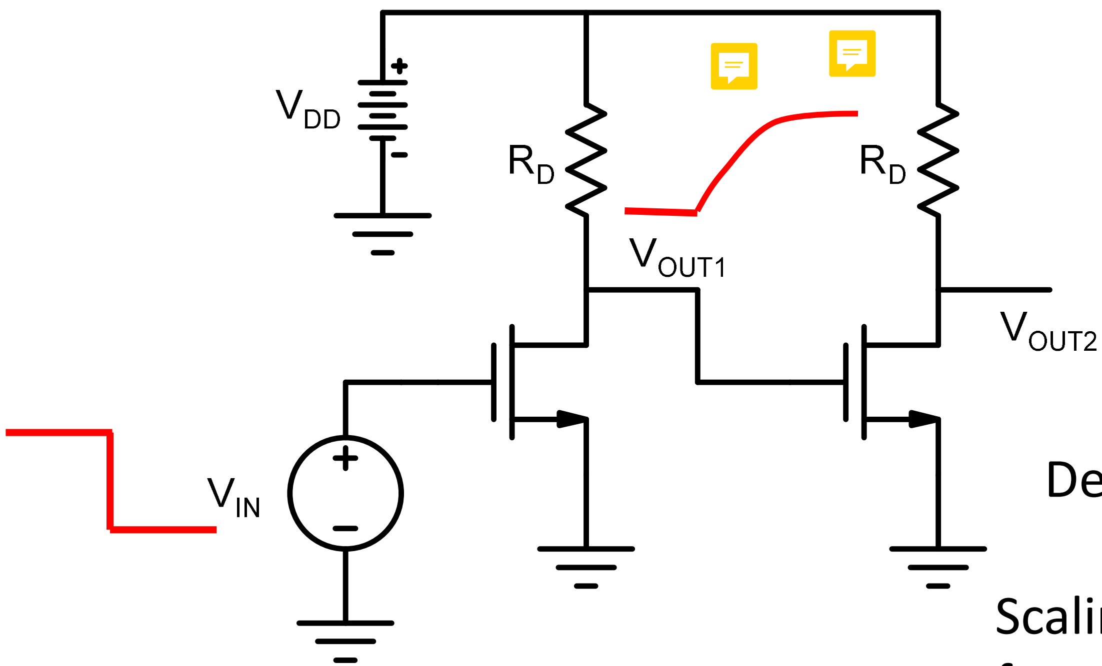


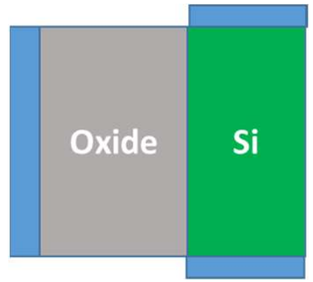



5V
V_DD
R_D
1.5k
D
5V
V_OUT
< 0.5V
G
0V
V_IN
5V
S


4.0x10^-3
3.0x10^-3
2.0x10^-3
1.0x10^-3
0.0
IDS (A)
0
1
2
3
4
5
VGS (V)







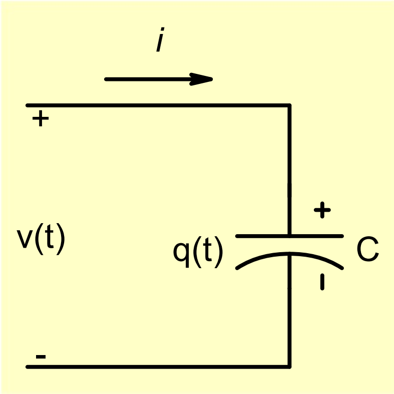
Delay due to RC charge/discharge

Scaling down of Transistor size leads to faster circuits

Capacitance

Two sheets of conductors separated by a layer of insulating material

– The insulating material is called dielectric. This could be air, polyester, …



$$q = C \times v$$

Coulombs

Farad

Volt

$$i = \frac{dq}{dt}$$

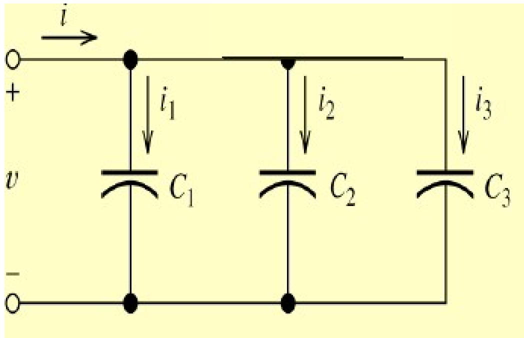
$$i = C\frac{dv}{dt}$$

$$v(t) = \frac{1}{C}\int_{t_o}^{t} i\,dt + v(t_o)$$

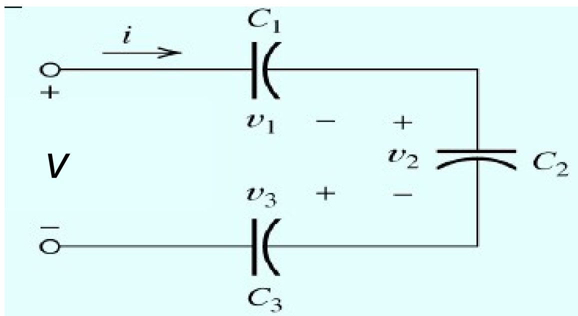
$$w_c(t) = \frac{1}{2} C \times v_c^2(t)$$

For dc or steady state when the voltage does not vary with time $i = 0$

A capacitor under dc or steady state acts like an open circuit

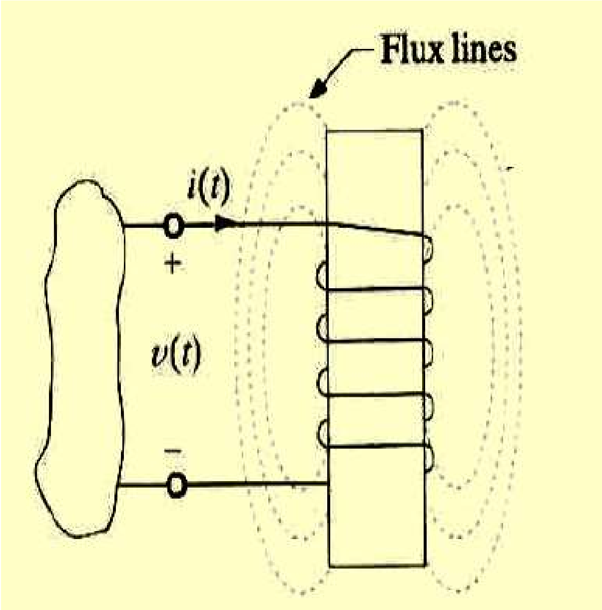


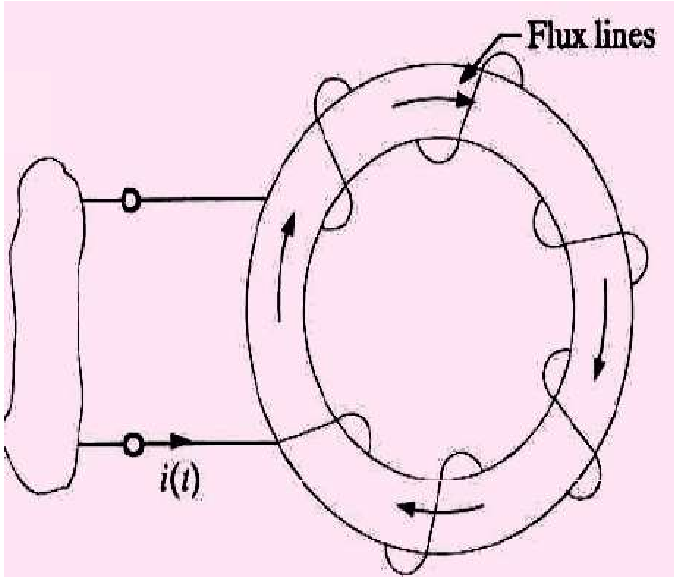
$$C_{eq} = C_1 + C_2 + C_3$$



$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Inductance

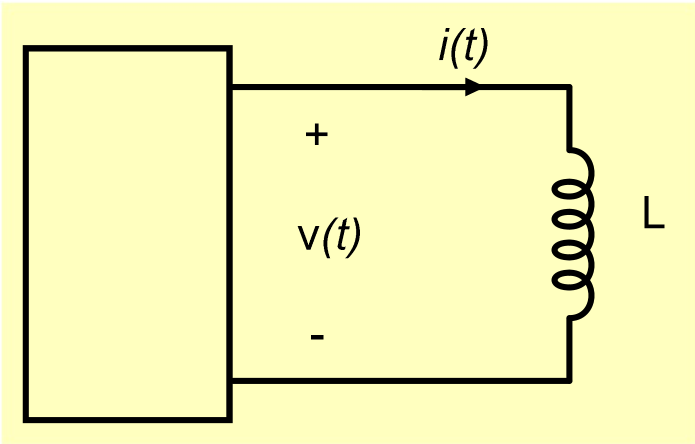




$$\phi = L \times i$$

A time varying flux causes voltage to appear across the device terminals

$$v = \frac{d\phi}{dt} = L \times \frac{di}{dt}$$

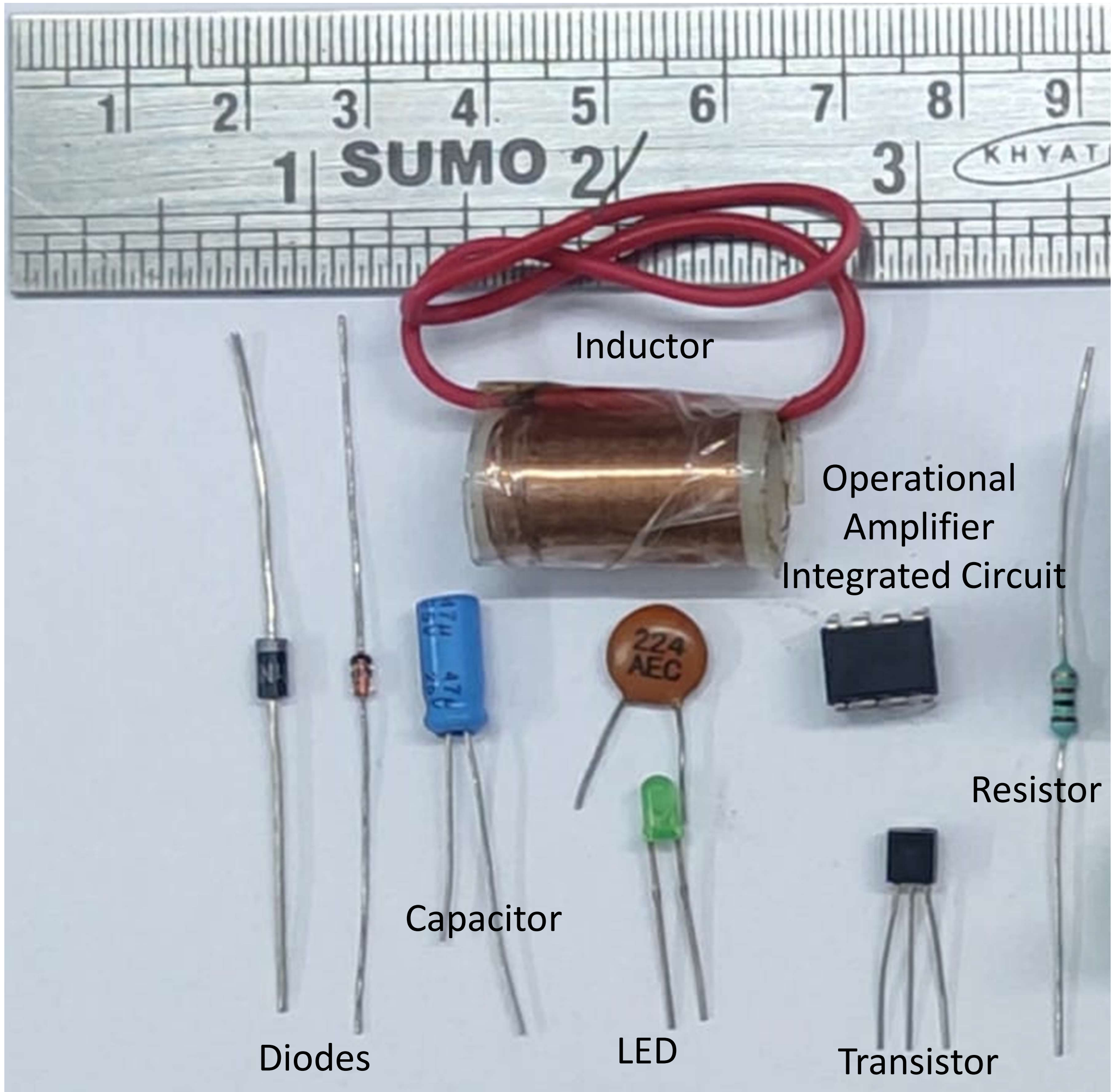


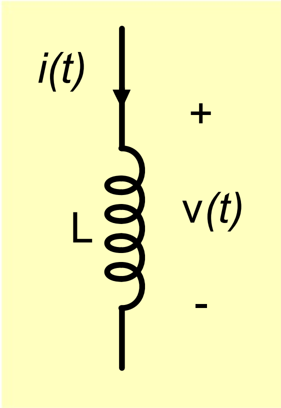
$$v = L \times \frac{di}{dt}$$

Henry

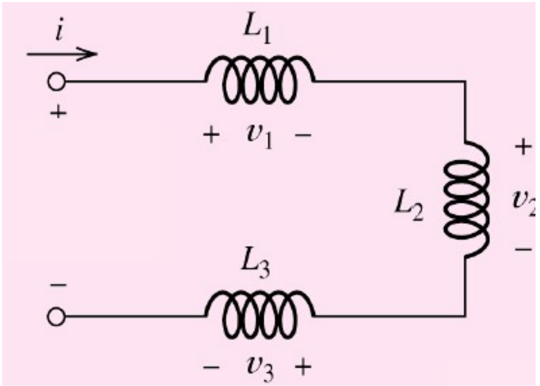
For dc or steady state when the current does not vary with time $\boxed{v = 0}$

An inductor under dc or steady state acts like a short circuit

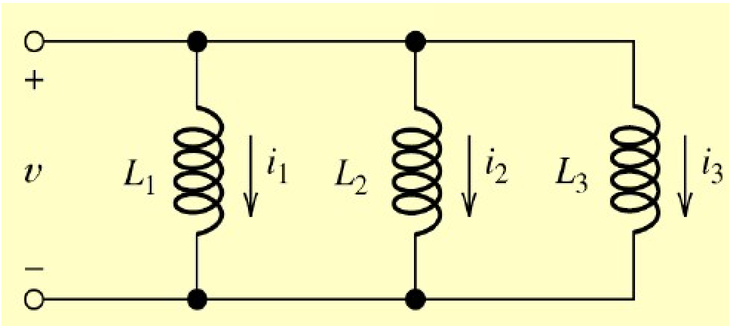

1
2
3
4
5
6
7
8
9
1
SUMO
2
3
KHYAT
Inductor
Operational
Amplifier
Integrated Circuit
224
AEC
Resistor
Capacitor
Diodes
LED
Transistor



$$w_L(t) = \frac{1}{2} L \times i^2(t)$$



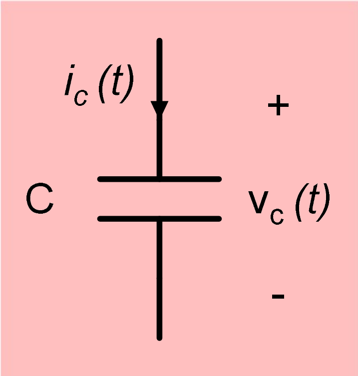
$$L_{eq} = L_1 + L_2 + L_3$$



$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

Two important concepts

Voltage across a capacitor cannot change instantaneously

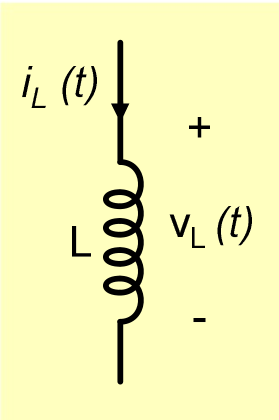


$$i_c = C\,\frac{dv_c}{dt}$$

$$v_C = \frac{1}{C}\int i_C(t)\,dt$$

Instantaneous change implies infinite current!

Current through an inductor cannot change instantaneously

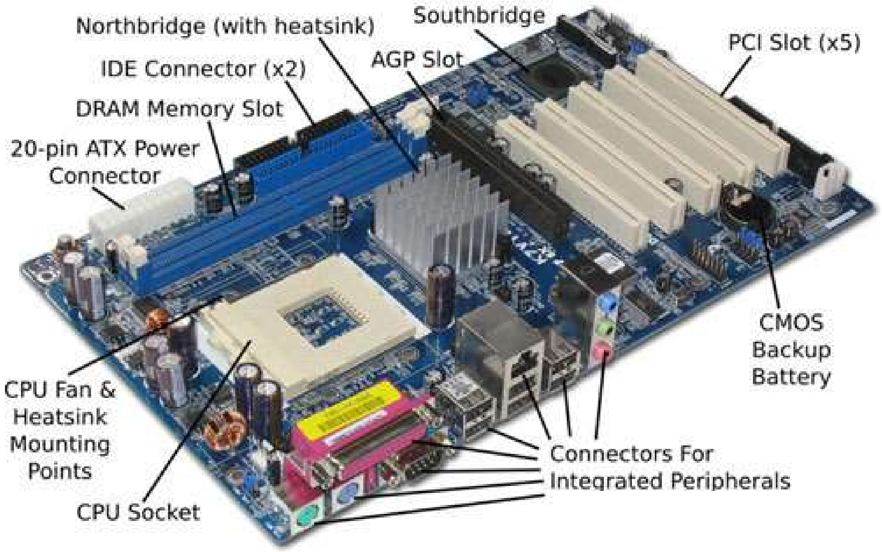


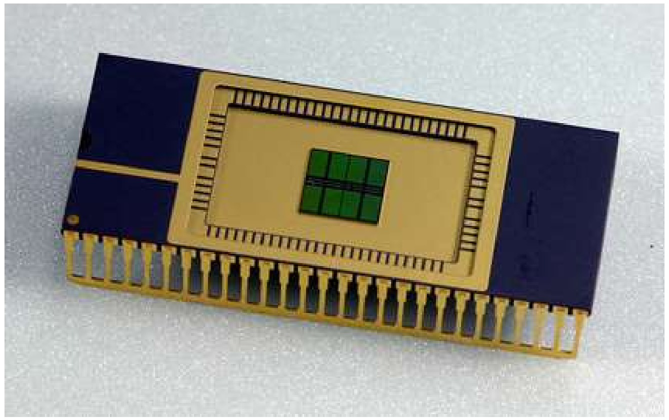
$$v_L = L\,\frac{di_L}{dt}$$

$$i_L = \frac{1}{L}\int v_L(t)\,dt$$

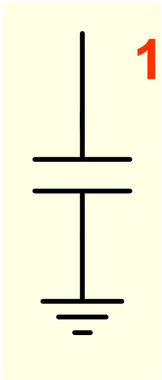
Instant change in voltage implies infinite voltage!

DRAM

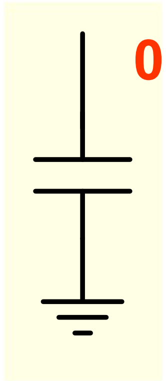




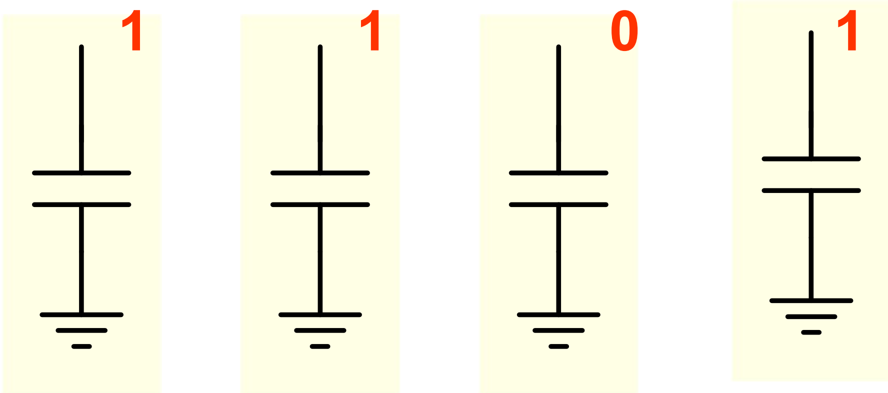
Basic Storage Unit is a capacitor



$Q > Q_1$



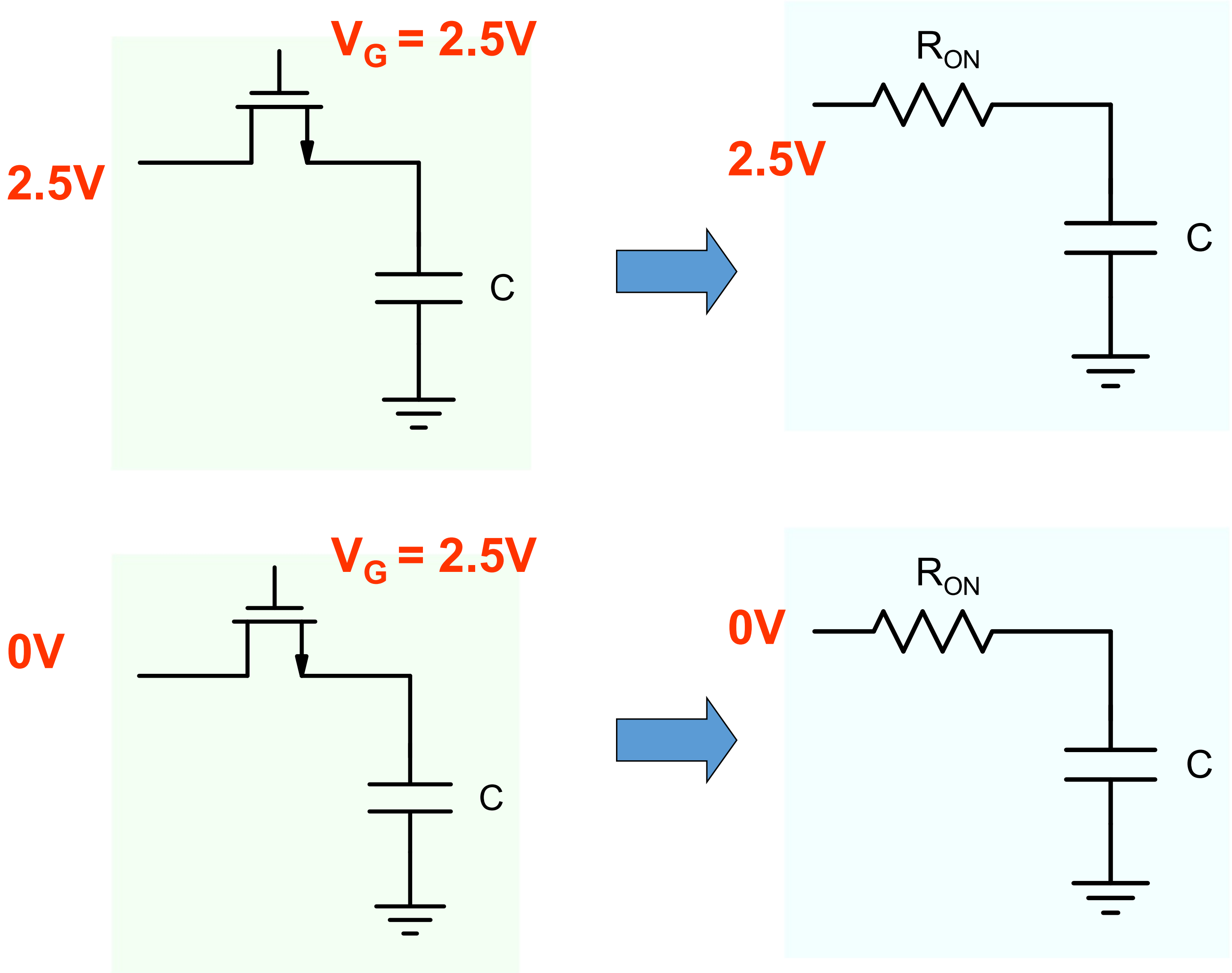
$Q < Q_0$

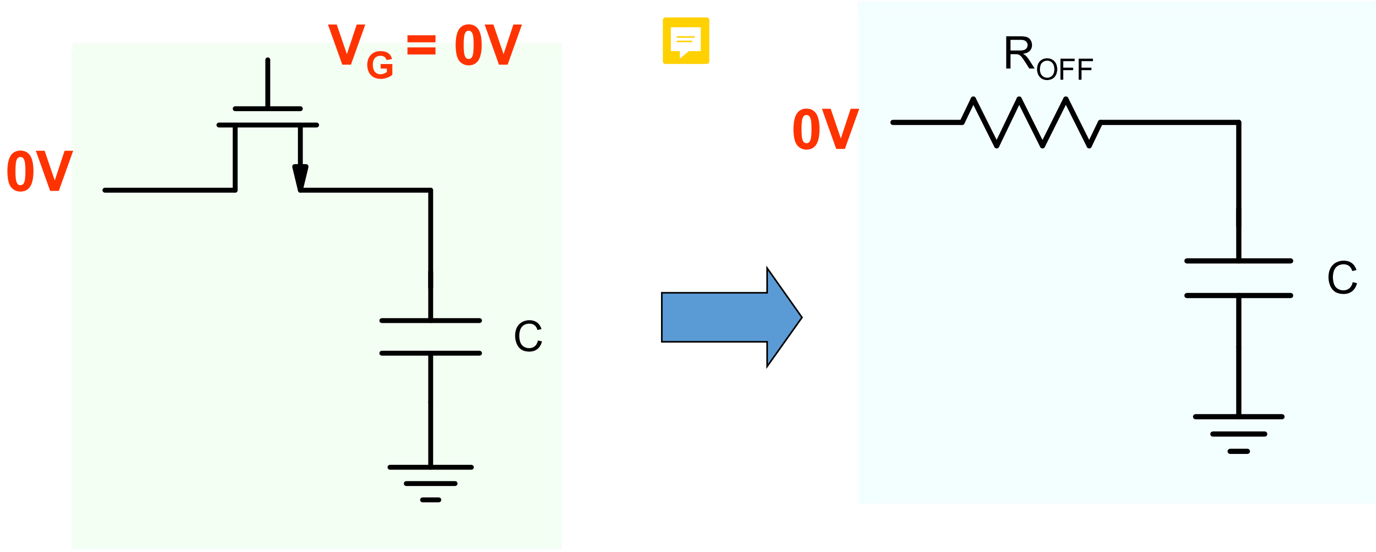


1101 in binary number format represents number 13

Each capacitor can store 1 bit of information

How do we store charge on the capacitor?

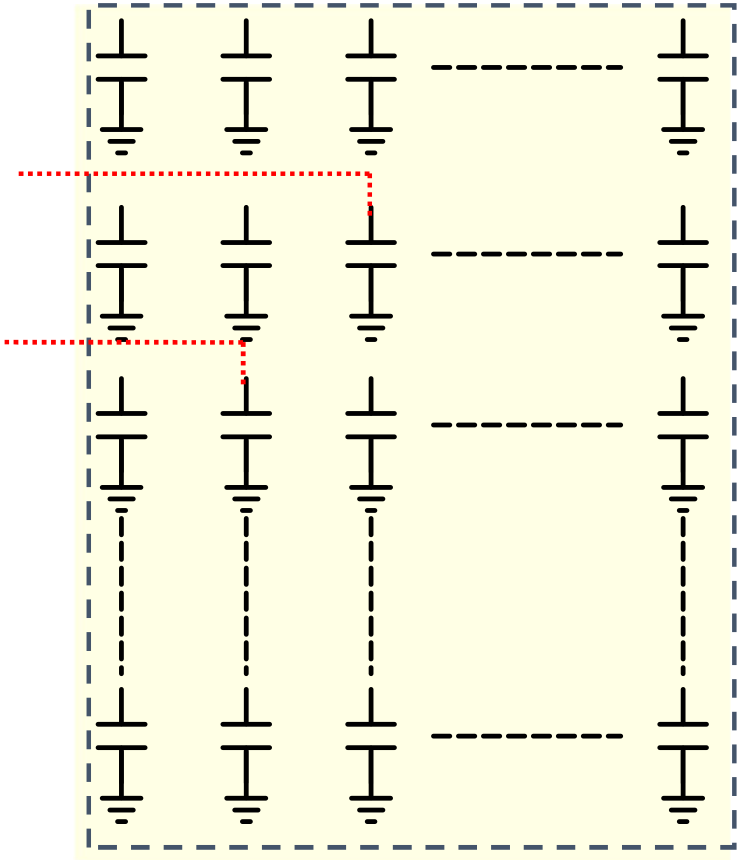


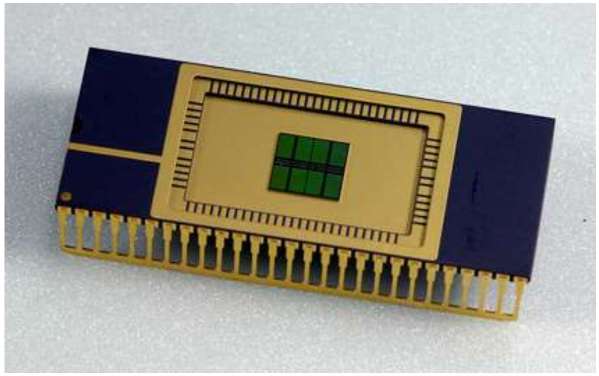


$V_G = 0V$
0V
C
R_{OFF}
0V
C

Why do we require transistor switches?

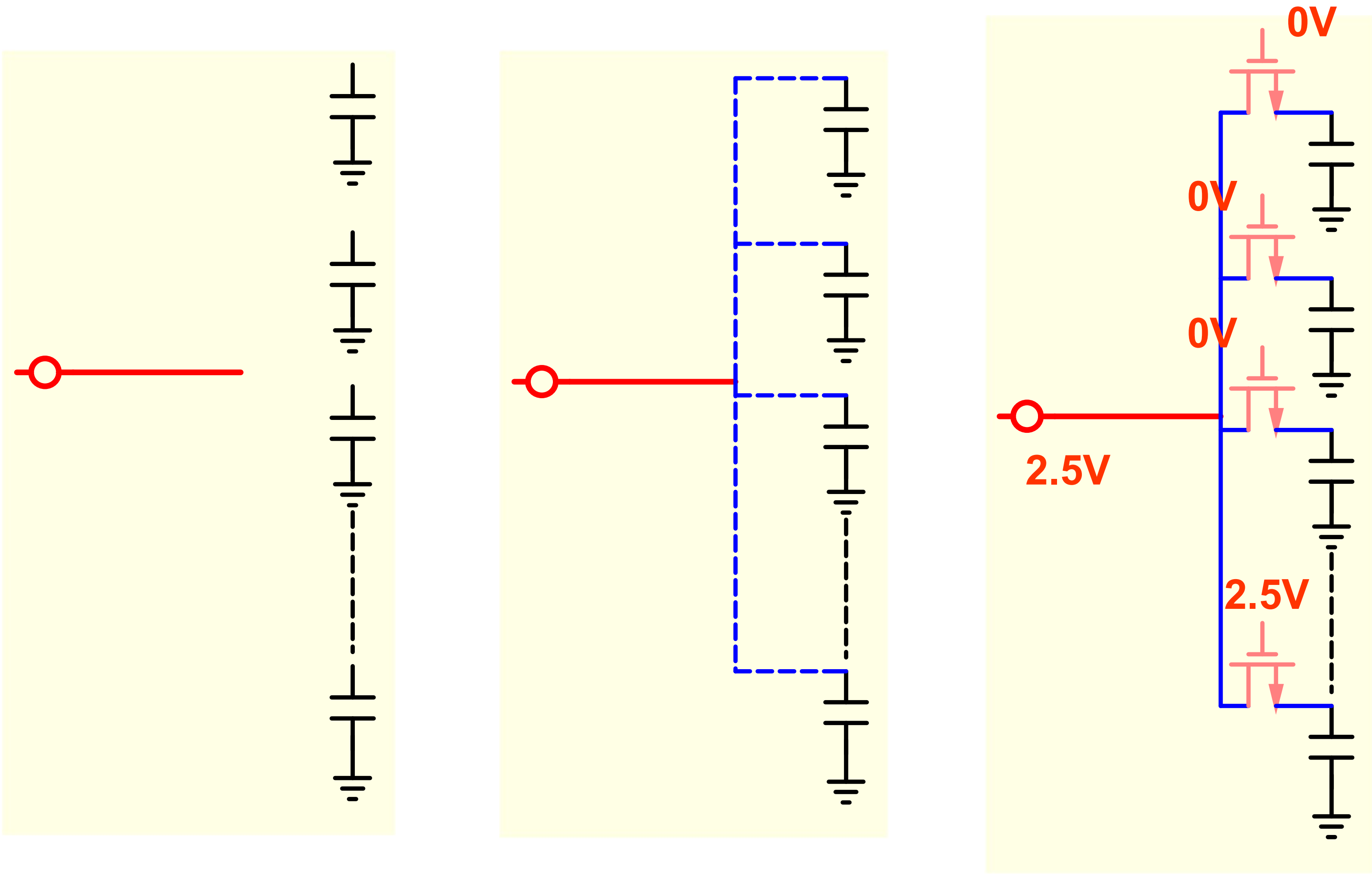
We have billions of capacitors in our overall memory ! How do we access them?





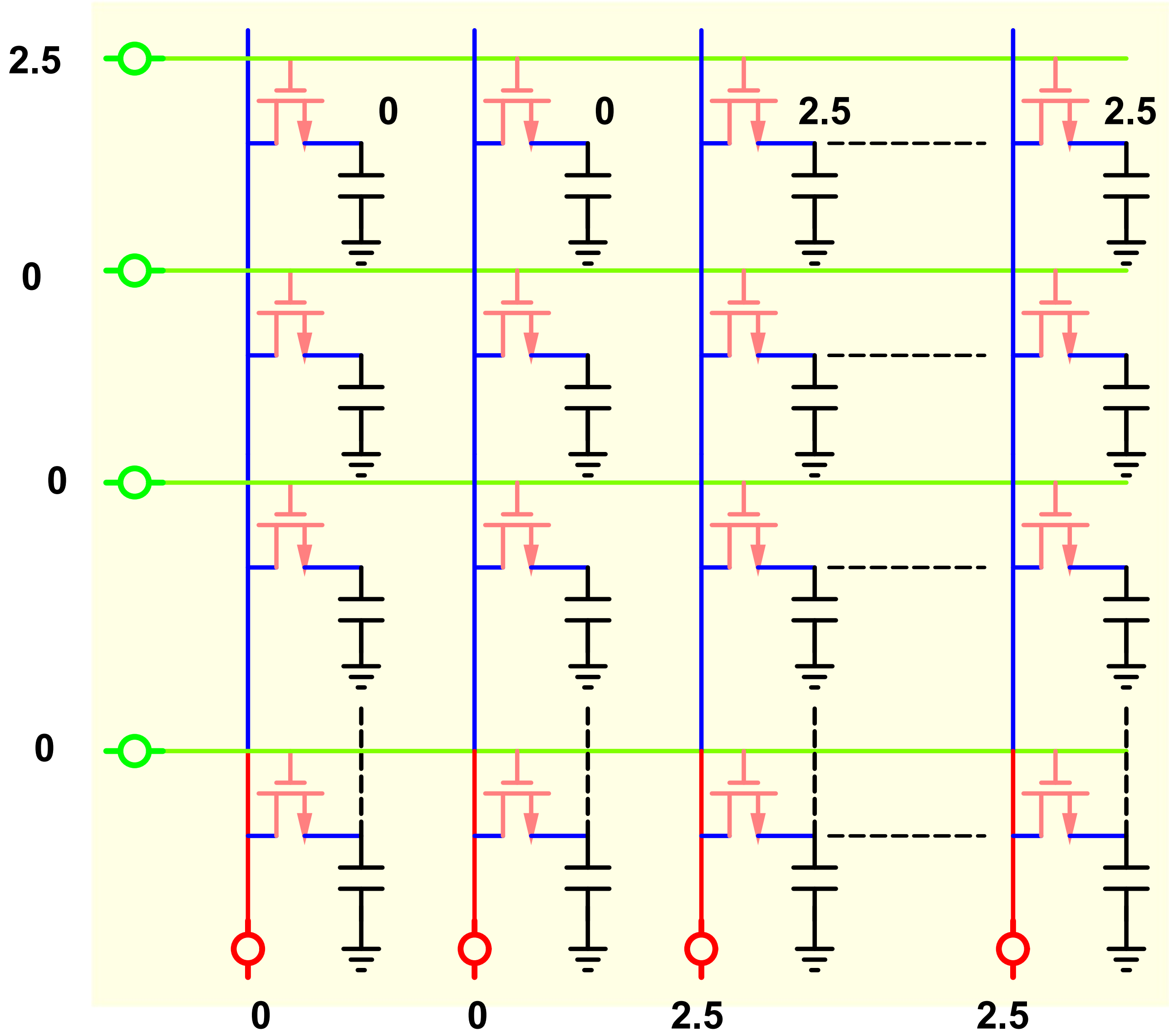
We do not have enough pins to individually access each capacitor !

One pin has to be connected to several capacitors !

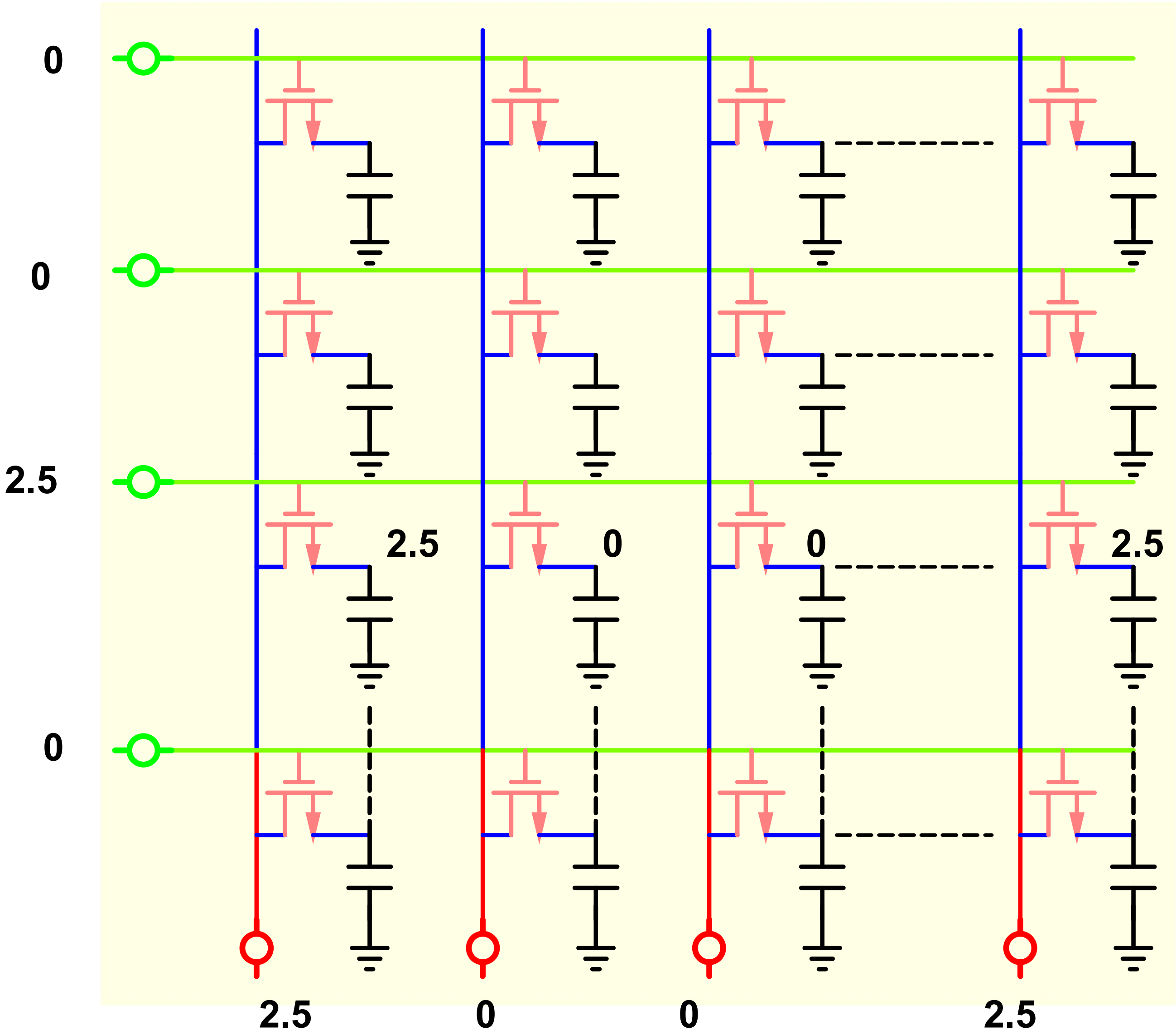


We can charge several capacitors through one single pin

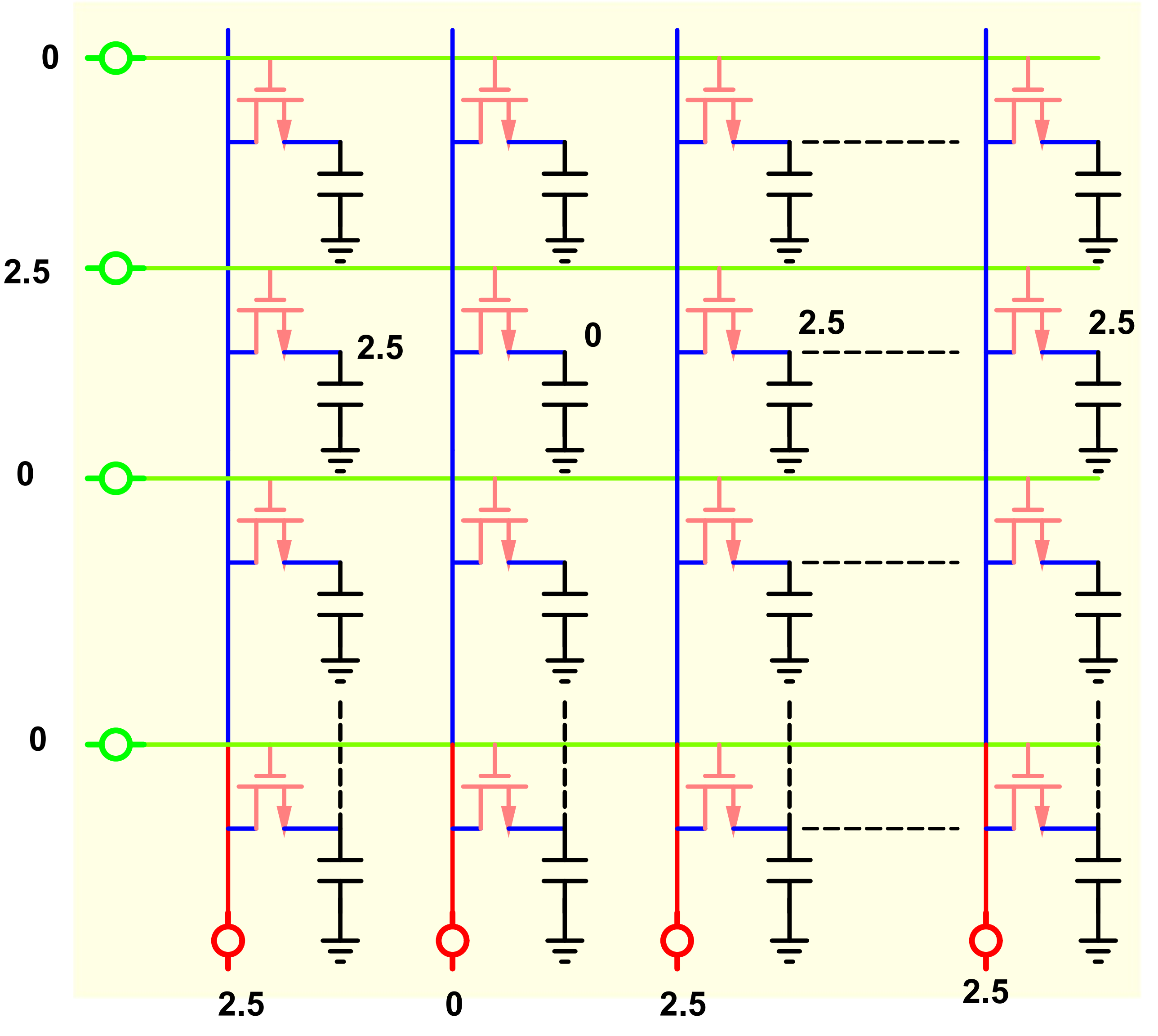
We can see the savings in pins now !



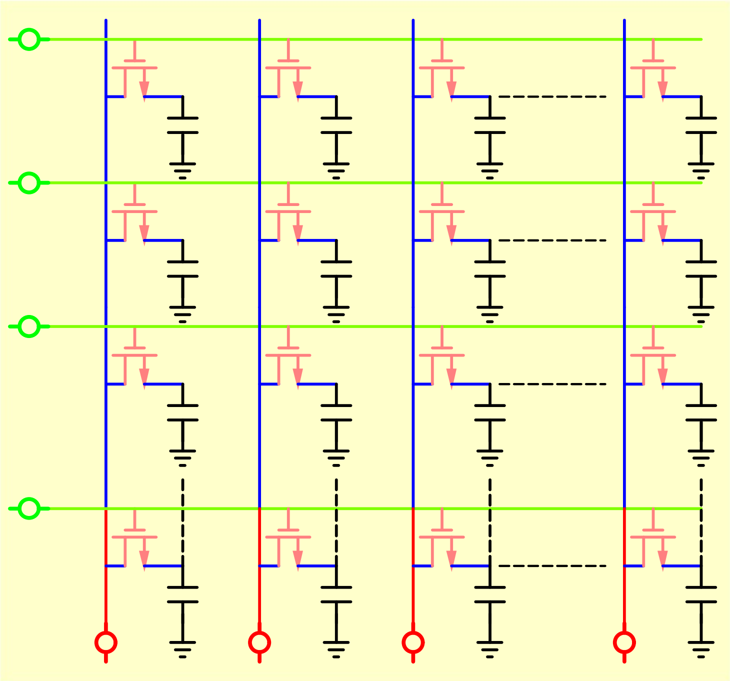
We can see the savings in pins now !

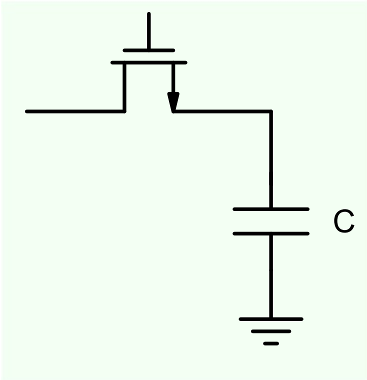


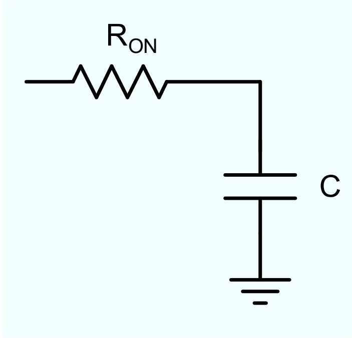
What about reading the memory?



Writing is sequential in nature

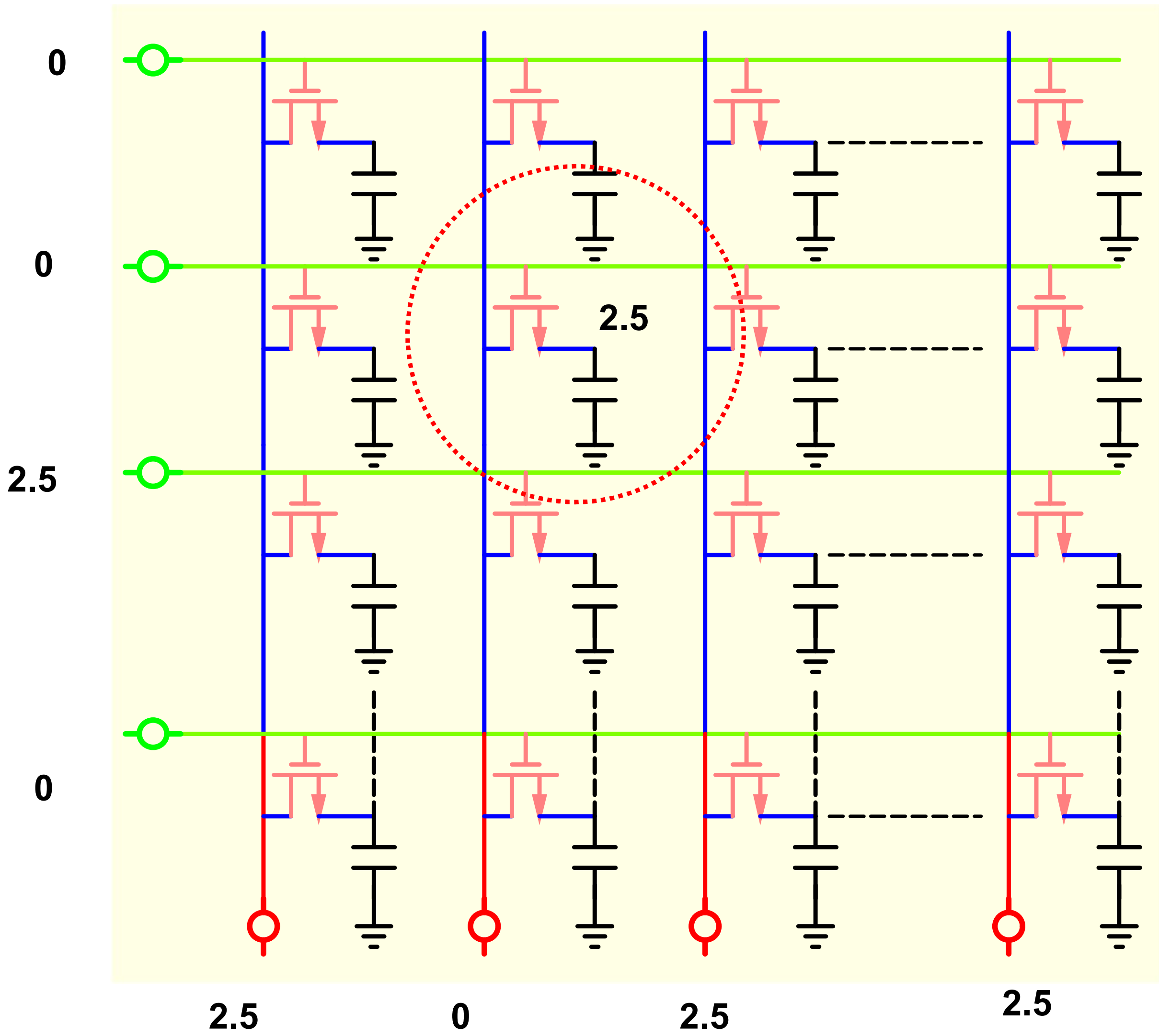


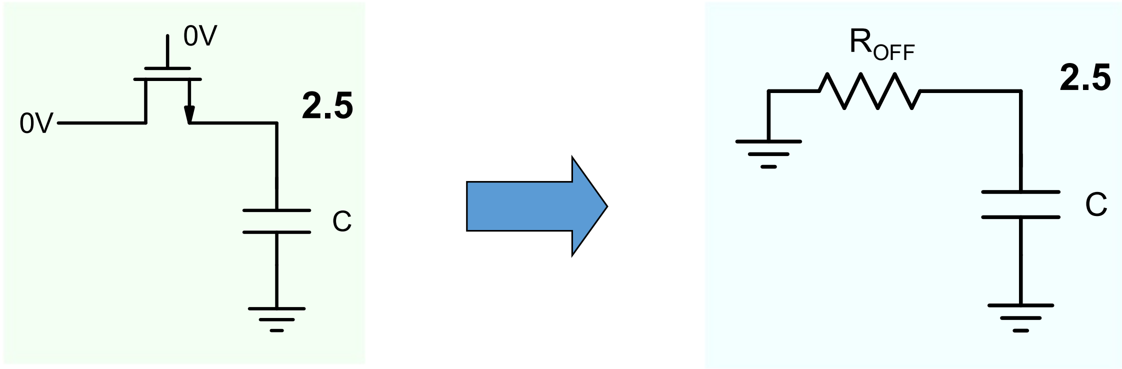




Make C as small as possible for fast memory. This also helps in making dense memory !

Over time, the capacitor loses charge





The memory cells need to refreshed periodically. Hence the name dynamic RAM